

26. POLYURETHANE RETAINERS FOR BALL BEARINGS

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SUMMARY

Evaluation of a new ball bearing retainer material is reported. A special composite polyurethane foam ball retainer has been developed that has virtually zero wear, is chemically inert to hydrocarbon lubricants, and stores up to 60 times as much lubricant per unit volume as the most commonly used retainer material, cotton phenolic. This new retainer concept shows promise of years of ball bearing operation without reoiling, based on life testing in high vacuum.

INTRODUCTION

The life and performance of spacecraft ball bearings are dependent on reliable operation of the ball retainer. For many bearing applications, where the lubricant supply must be sealed in during assembly, the retainer should serve as a lubricant reservoir as well as a ball-holding and separating device. Retainer selection, therefore, must be based on:

- High oil-holding capacity (absorptivity)
- Good oil retention and feed characteristics
- Physico-chemical inertness and stability
- Low friction and wear
- High strength, but good resiliency
- Low cost with good machinability

The most widely used porous ball retainer material is laminated cotton cloth base phenolic tubing. Although many other materials have been tested and a few achieved limited usage, cotton-reinforced phenolic is still the workhorse in a ball bearing design. Because only part of the oil impregnated into such a retainer will transfer to the bearing balls, ultra-long-life oil supply is limited by low absorption retainers. (For example, a typical 90 mm bore, light series angular contact bearing retainer of 1 percent porosity phenolic will hold only 0.4 gram of hydrocarbon oil.)

RETAINER DEVELOPMENT

Because of the difficulties in applying commercial phenolic, a search for alternate materials for bearing retainers has been conducted. Materials evaluated include sintered bronze, sintered aluminum, sintered polyimide, polyurethane composite foams, and laboratory-fabricated cotton phenolic laminates.

Numerous bearings have been tested using laboratory-fabricated phenolic and polyurethane foam. Bearings using polyurethane composite foam retainers have been operated successfully for periods up to 1 year in vacuum at 100 rpm. Polyurethane composite foam retainers have shown extremely low

wear compared to cotton phenolic, sintered bronze, and sintered aluminum and are capable of storing up to 60 percent by volume of lubricant. The oil transfer characteristics are good in that oil is rapidly transferred from the retainer to the balls and races when an insufficient oil film exists and the transfer stops as soon as an adequate oil film is reestablished. Chemical tests and accelerated high temperature aging tests indicate the retainer is inert and does not react with nor degrade hydrocarbon lubricants and that the retainer maintains adequate mechanical properties for long-term applications (longer than 3 years).

The composite foam is a special high porosity material with controlled pore size to accurately control oil storage and capillary flow rate. Vacuum outgassing tests have shown very low volatility ($<6 \times 10^{-10}$ gm/cm²/sec at 50° C). Because the foam is a flexible material, designs using a rigidizing frame are necessary. This type of design achieves more favorable thermal expansion match with the bearing metal parts. Bearing retainers in sizes from R-4 to 150 mm bore have been built and tested (see Figure 1). Bearings equipped with these retainers have survived vibration up to 12 g at frequencies from 20 to 2000 Hz, temperatures from 30° to 150°F, and speeds from 60 to 3600 rpm. Running torque of composite foam retainer bearings can be somewhat higher than that of cotton phenolic (approximately 10 percent) and torque variation (i.e., torque noise) is about the same as for cotton phenolic.

RETAINER DESIGN USING POLYURETHANE FOAM

Because of the high flexibility of the polyurethane composite material (Shore A 30 hardness), a rigid frame is necessary to maintain the shape of the retainer. Various designs of metal frames have been used successfully. Figure 1 illustrates two sizes of composite metal frame retainers.

The polyurethane composite foam has inherent properties that make it ideal as a ball bearing retainer material for many applications. It is a tough material with fairly good tear strength (22 pli) and an extremely low wear rate. The pore size, shape, and distribution provide a large lubricant storage area with a feed rate that varies favorably according to the oil film thickness. Table 1 summarizes some of the properties of interest.

TABLE 1. POLYURETHANE COMPOSITE FOAM PROPERTIES

Property	Value
Density (dry)	0.398 gm/cm ³
Density (oil impregnated)	0.994 gm/cm ³
Oil per unit volume	0.597 gm/cm ³
Oil per unit volume for phenolic (for comparison)	0.046 gm/cm ³
Pore size (diameter)	10 microns
Hardness	30 Shore A
Tensile strength	115 psi minimum
Tear resistance	22 pli minimum
Operating temperature range	0 to 70°C

Accelerated aging tests of the oil-impregnated foam (Apiezon C oil with 5 percent lead naphthate EP additive) and unimpregnated foam done at 250°F in vacuum for 408 hours showed no significant changes from aging except for a hardness increase from Shore A 30 hardness to Shore A 35-40. Infrared analysis, carbon hydrogen elemental analysis, and thermogravimetric analysis results showed no difference due to aging of the foam or the oil.

The steady-state weight loss rate of the foam was measured at 50°C in vacuum and was found to be 5.5×10^{-10} gm/cm²/sec.

POLYURETHANE COMPOSITE FOAM MATERIAL PERFORMANCE

A series of material performance tests evaluated performance of the foam material prior to fabrication of retainers for ball bearings. Wear tests compared friction, wear, and oil transfer rates of the urethane material with phenolic and other candidate retainer materials. These tests were run in air at laboratory ambient conditions in a Class 10,000 laminar flow room. Wear test samples were run on a half-inch diameter stainless shaft driven at 300 rpm. A 3 pound force was applied by the coil springs in the specimen holders, pushing each wear test sample against the shaft. All test samples were impregnated with Apiezon C oil with a lead naphthate EP additive. Barrier coatings were applied in bands around the shaft between the samples. The tests were run for 1 month with the results as follows:

<u>Sample</u>	<u>Results (after 1 month)</u>
Sintered aluminum, standard	High wear, catastrophic failure in 8 days
Special alloy sintered aluminum	Unacceptable wear by end of test
Phenolic	Small wear scar and debris, shaft discolored
Sintered polyimide	Less wear than phenolic, shaft discolored
Sintered bronze	Wear comparable to phenolic, no discoloration of shaft
Composite urethane foam	No detectable wear, no shaft discoloration

A notable result of this initial test was the complete absence of wear, debris, or shaft discoloration for the polyurethane foam sample. Tests were continued for a second month with the same result.

Friction Tests

A series of friction coefficient measurements was made on the specially constructed friction test apparatus shown in Figure 2. Friction coefficient was measured between the rotating ball (19/32 inch diameter) and a fixed flat block of polyurethane foam over a range of speeds, normal forces, and oil quantities, and for two block thicknesses. The friction force was measured by using a force transducer consisting of a cantilever spring and differential transformer displacement transducer. This was calibrated against a Chatillon spring type force gauge. The results are shown in Figure 3.

The high values of friction coefficient and the higher coefficient for low normal forces may be due in part to the method of measurement. The 19/32 inch diameter ball penetrated on the order of 0.005 inch into the foam with 0.1 pound normal force applied. This penetration leads to a surface under tension in the contact region and may result in higher friction. (See ref. 1.)

Oil Transfer Tests

Lubricant transfer characteristics were measured on blocks of foam impregnated with Apiezon C oil mixed with a lead naphthanate additive. A special fixture was constructed to continuously remove the oil film transferred from an impregnated foam block to a large 440C stainless ring. Successive weighings of the foam block provided data on oil transfer rate as the oil was depleted from the block. Other measurements were also made without removal of the transferred film to evaluate oil transfer versus already transferred film thickness. A foam wheel in a freon bath was used to remove the transferred oil film. The oil transfer test apparatus is shown in Figure 4.

As shown in the oil transfer data (Figure 5), the transfer rate is highest for the fully impregnated condition and then decreases with running distance. This decrease may partially result from the abnormally high oil transfer rate imposed on the test sample to provide data in a reasonable time interval. In a ball bearing, the transfer rate would be far less because of the established oil film, as shown in the following experiment.

The same apparatus used for measuring oil transfer with continuous removal was used to measure oil transfer as a function of previously transferred oil film thickness. Results have shown that after three or four revolutions of the stainless ring, an equilibrium oil film thickness is established and that continued rotation up to thousands of revolutions results in no further measurable oil transfer. The equilibrium film thickness was found to be on the order of 33 microinches for a test block almost fully impregnated (surface oil removed) and this decreased to 20 microinches after about one-third of the oil had been transferred out of the block by continuous removal of the oil from the ring. The interesting characteristic of the polyurethane foam was the very rapid transfer of oil to a dry surface followed by an abrupt end of oil transfer once the equilibrium oil film was established.

RETAINER/BEARING PERFORMANCE

A number of short-term performance evaluation tests such as oil transfer, vibration, torque noise, and thermal aging have been conducted on bearings equipped with polyurethane composite foam retainers. In parallel with these tests, 20 bearings with polyurethane composite retainers are currently operating in thermal-vacuum life tests.

Oil Transfer Tests

Various oil transfer measurements were made on a 2.362 inch diameter bore by 3.740 inch outside diameter bearing (440C material) and a polyurethane foam retainer. Oil transfer from the retainer to the balls and races of the bearing was measured by successively weighing the retainer. The test procedure was as follows:

- 1) Freon-rinse balls and races to remove oil
- 2) Weigh retainer
- 3) Assemble bearing
- 4) Run bearing 100 rpm, 45 pound axial preload, laboratory ambient conditions, various time intervals from 1 minute to 17 hours

- 5) Disassemble bearing
- 6) Go back to step 1 above

At one point, the freon rinse was not done for several cycles to evaluate oil transfer as a function of amount of oil on the metal surfaces. The total amount of oil transferred per run appears to be independent of run duration. Both the 1 minute and the 15 hour, 49 minute runs resulted in the same amount of oil transfer from the retainer to the balls and races, as shown in Figure 6. This suggests that the transfer mechanism is dominated by the oil film thickness on the balls and races and that oil transfer stops after a given oil film is established.

Bearing Torque Test Results

Bearing torque and torque noise were measured in air over a speed range of 45 to 150 rpm on nine bearings with urethane foam retainers. Figure 7 shows torque and torque noise measurements on a typical bearing. The measurements were compared to similar data on phenolic retainers and the torque values ranged from the same to 20 percent lower on the bearings equipped with phenolic retainers.

Vibration Test

A vibration test was run on a polyurethane foam equipped bearing. The test was run from 1.5 to 25 g at frequencies of 5 to 2000 Hz. Inspection of the bearing and retainer after vibration showed no damage nor problem with the polyurethane foam retainer. There was no evidence that vibration caused oil loss from the foam. The test was repeated on 16 other bearings of three sizes with polyurethane retainers, and no damage, oil loss, nor degradation of performance was found after vibration.

Wettability Tests

A 90 hour vacuum test on one 3.543 inch diameter bearing with a polyurethane foam retainer lubricated with Apiezon C oil with a lead naphthanate additive was conducted. The bearing was run at 60 rpm and with a 60 pound axial load. The test pressure was 1×10^{-5} Torr and the test was done at ambient temperature. The bearing metal parts had previously been run in vacuum without a retainer and were 100 percent wetted with the same oil. Inspection of the bearing after the 90 hour vacuum test with the polyurethane foam ball riding retainer installed showed no evidence of nonwetting of balls nor races. The oil quantity in the bearing was also normal.

Temperature Test Results

Eight bearings with foam retainers were subjected to simulated storage and transportation exposure for approximately 3 hours at each temperature extreme of -50° and $+150^{\circ}$ F. Subsequent performance of these bearings in life tests was normal. Torque on a pair of bearings operating in vacuum was measured over a temperature range of 40° to 115° F, with results comparable to a similar phenolic-equipped bearing, as shown in Figure 8.

Life Test Results on Polyurethane Foam Retainers

Twenty-two bearings equipped with polyurethane retainers are currently under life test in high vacuum. There have been no failures and no indications of degradation in any of the tests, some of which have been operating for over a year. Figure 9 shows the duration of the various tests. These bearings are mounted and preloaded to simulate despin bearing applications for communication spacecraft antennas. Figure 10 shows torque versus time for various test bearings. One test was interrupted after 1 year of operation and visual inspection showed no damage nor degradation and no evidence of retainer wear. The bearings were coated with thick oil films, and weight measurements indicated that over 97 percent of the initial oil in the bearing remained after 1 year of vacuum operation.

CONCLUSIONS

Experimental work on composite polyurethane foam as a ball bearing material has demonstrated certain characteristics that are superior to metal ribbon, cotton phenolic, and certain other types of retainers.

Tests of composite polyurethane foam have shown:

- 1) Lower wear rates than cotton phenolic, sintered bronze, sintered aluminum, and sintered polyimide.
- 2) Very low outgassing in vacuum (5.5×10^{-10} gm/cm²/sec at 50°C).
- 3) Good chemical stability and minimum physical properties change when aged in hydrocarbon oil at 150°F.
- 4) Rapid lubricant transfer until a film is established followed by diminished transfer, thus minimizing the risk of flooding.
- 5) Good performance in bearing high vacuum life tests for up to 12 months.

The friction coefficient is higher than for metal retainers or phenolic and ranges from 0.27 to 0.37.

Fabrication of this material to very close tolerances suitable for ball bearing retainers is difficult but attainable and, by using the metal backup structure, good dimensional control can be achieved.

The inherent high porosity and oil storage capacity make this material attractive as a bearing retainer material for long life, zero maintenance systems. Continuation of life tests currently in process will establish a test data matrix upon which to estimate the reliability of this concept.

REFERENCE

1. Nazarenko, P.V. et al., "Investigation of the Deformation and Sliding Friction of Polyurethane in the Presence of Lubrication," Kievskii Institute Inzhenerov Grazhdanskoi Aviatsii, Kiev, Ukrainian SSR, Mekhanika Polimerov, Vol. 5, March-April 1969, A69-35362.

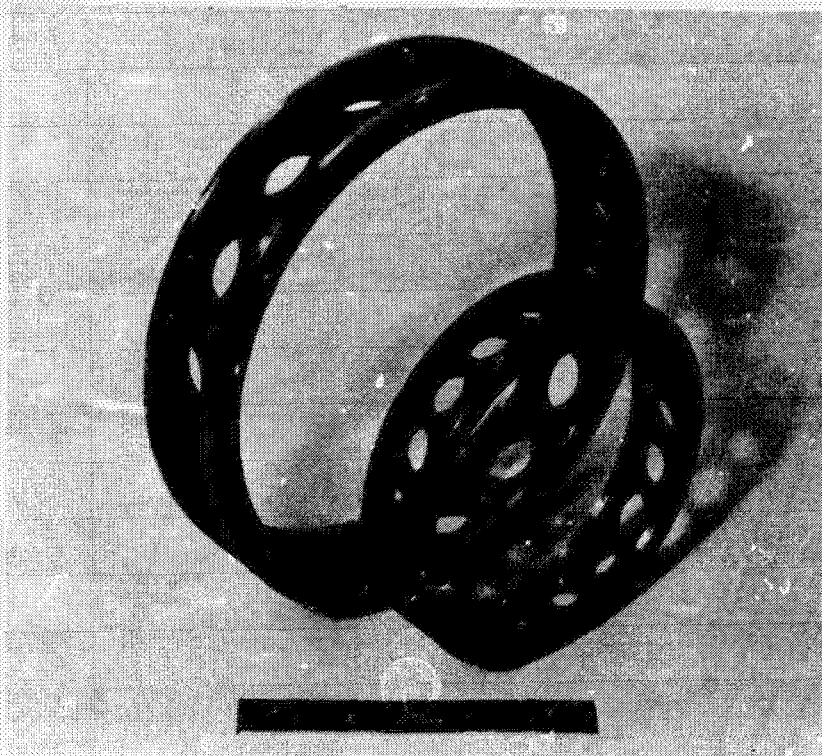


FIGURE 1. POLYURETHANE COMPOSITE BALL RETAINERS
(PHOTO 4R24412)

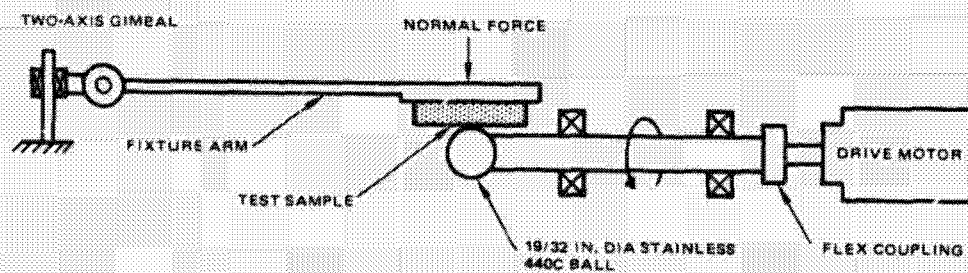


FIGURE 2. SCHEMATIC OF FRICTION TEST APPARATUS

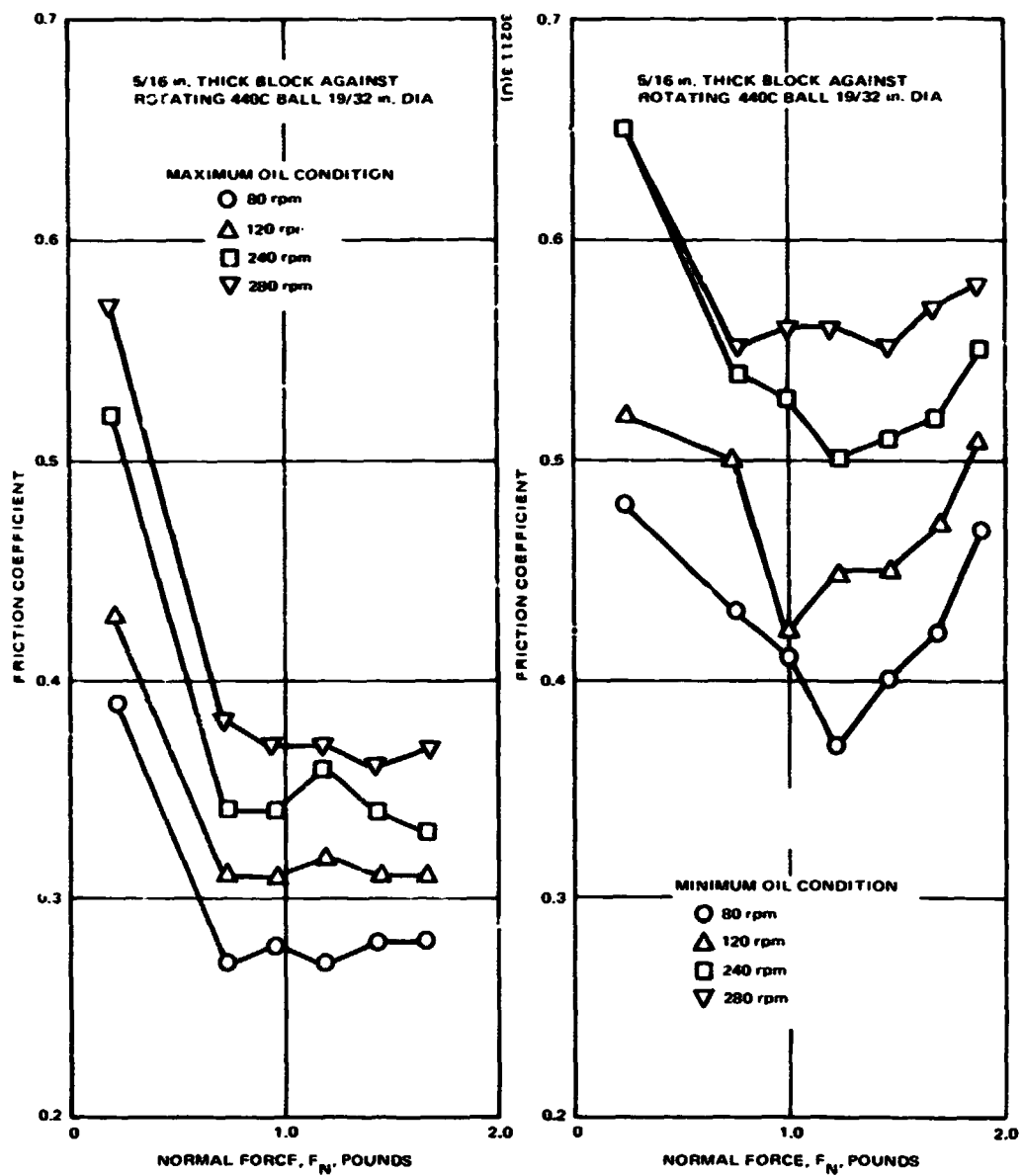


Figure 3.- Friction coefficient for polyurethane foam against stainless steel.

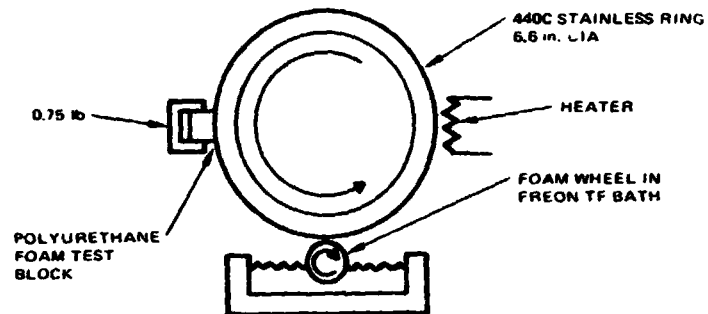


Figure 4. - Oil transfer test apparatus.

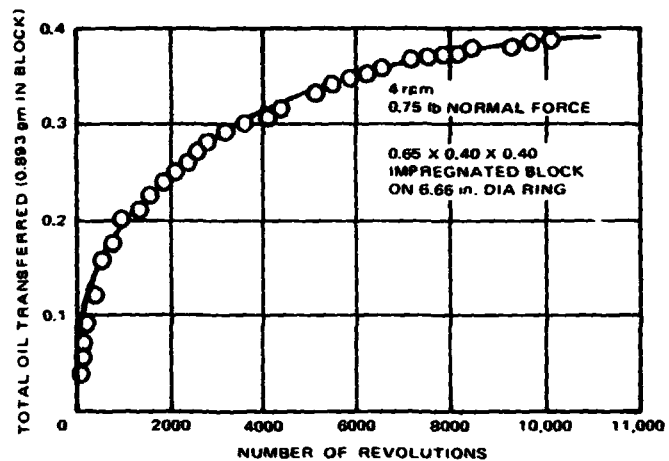


Figure 5. - Total oil transferred versus number of revolutions.

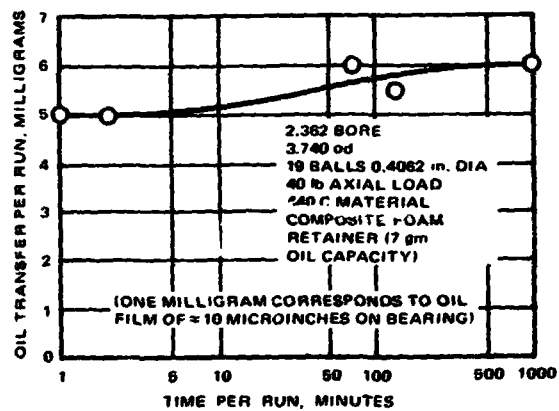


Figure 6. - Amount of oil transferred to dry bearing from composite foam retainer as function of running time.

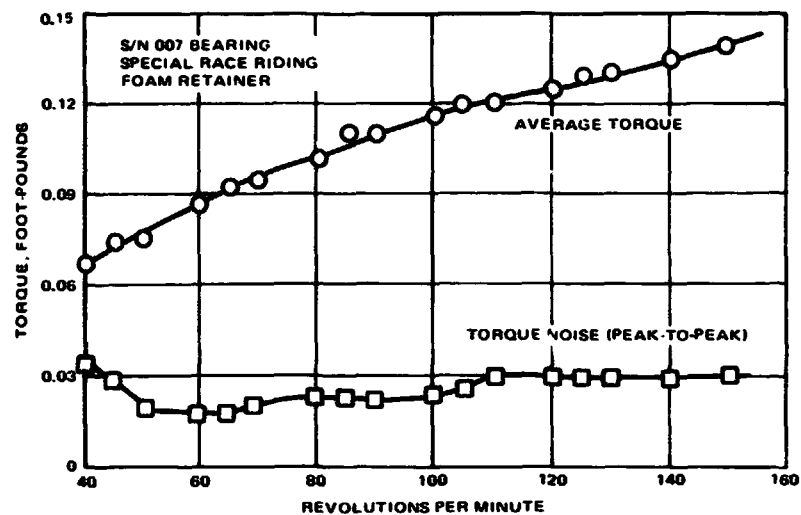


Figure 7.- 3.543 inch diameter bearing torque data.

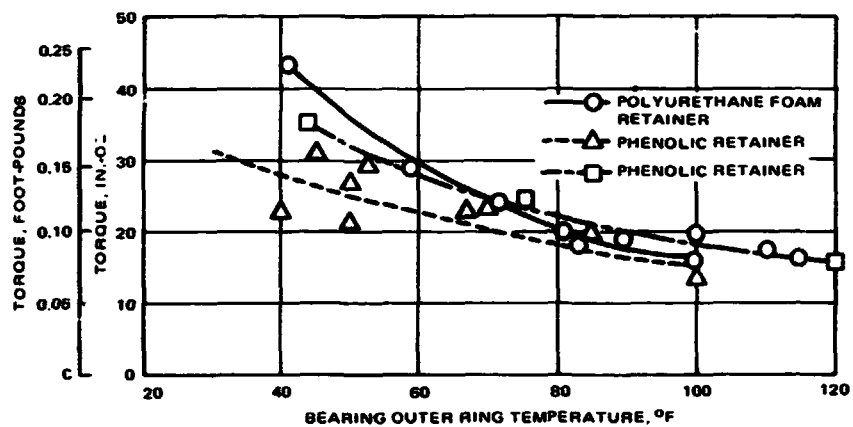


Figure 8.- Hot and cold temperature cycle 3.543 inch bore bearings (torque of two bearings) at 60 rpm.

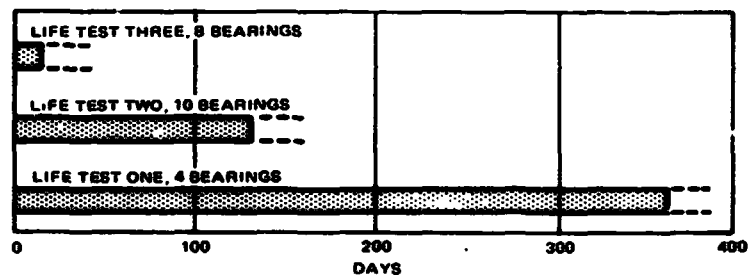


Figure 9.- Life test history chart (as of 10 May 1973).

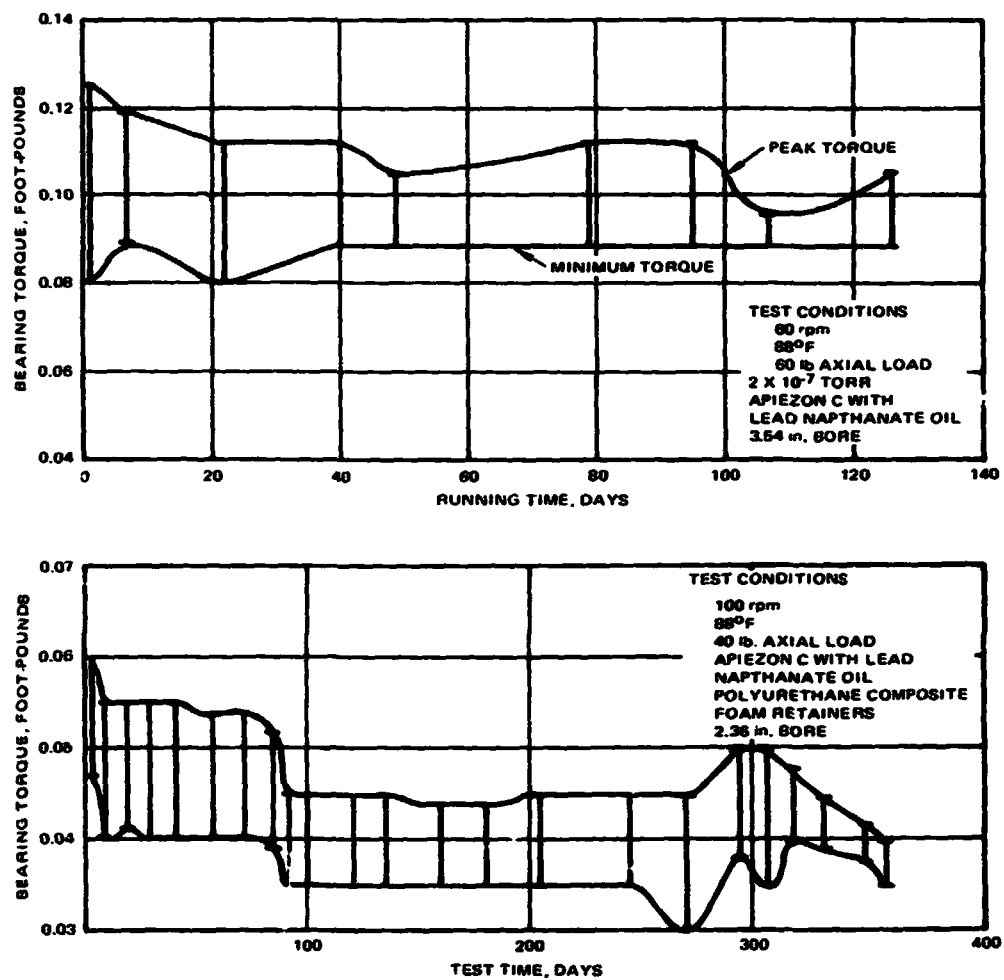


Figure 10. - Test bearing torque versus time for two bearings.